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DESIGN OF WATER WORKS FOR PRAIRIE DU CHIEN, WISCONSIN

by

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and

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Introduction

Prairie du Chien is the oldest settlement in Wisconsin. It existed as a village at the time of the French and Indian wars. Its traditions are manifold. Here it was that Jeff Davis, a dashing young lieutenant, won Gen. Taylor's daughter against her father's will. Old Fort Crawford has served as a quarry to such an extent that at present there are only a few stones left to mark the old site.

The city is situated on the east bank of the Mississippi River, a few miles above the mouth of the Wisconsin River. It is built on the sand and gravel, deposited to a depth of 100 to 150 feet in the ancient bed of the river. On the east it is bounded by towering bluffs of limestone rising to a height of about 375 feet above low water of the river. It is divided into four wards, as shown in Fig.4.

The purpose of this thesis is to design a water works system which will furnish ample fire protection, as well as water for all ordinary purposes, on the principal streets of the city. The number of streets to be served will be limited to those having a sufficient population or a location important enough to warrant the expense. The design must be economical. It will be important to make the first

cost as low as possible. However, the principal purpose in the matter of cost will be to provide for a system which will serve the purpose most effectively at a minimum annual cost of operation within reasonable limits of first cost.

To present briefly the method of treatment, the following synopsis is given:

A

SOURCES OF SUPPLY

Quantity Required.
    Population.
    Consumption.

Source of Supply
    General
    River
    Artesian Wells
    Ground Water
        General
        Present Wells
        Rainfall
        Flow
        Location
        Method of Collection
        Number of wells

B

WORKS OF DISTRIBUTION

1. Distributing System
    Pipe Lines
        Introduction. Location. General Problem.
        Assumption. Calculation. Conclusion.

1. Distributing System---cont.

    - Location of valves and hydrants.
    - Cost.

2. Pumping Machinery

    - Direct Pumping
    - Kind of pumps
    - Methods of operation
    - Rate
    - Size of pumps
    - Efficiency and duty
    - Cost of plants

3. Reservoirs

    - General
    - Elevation
    - Steel tanks
    - Masonry
        - Form
        - Source of stone
        - Design
        - Cost

- - - -

Annual Cost of Operation.

Total Cost of Plans 2 and 4.

Conclusion.

General Outline

The main topics are: A, Source of Supply; B, Works for Distribution; Total Cost of Works,; and the Conclusion.

In considering the sources of supply it is necessary to know the quantity required, both in the future as well as at present. Therefore the population and probable consumption per capita will determine the quantity required.

There are three possible sources of supply: the river, the artesian wells, and the ground water. With due consideration of the quality, the cheapest source would be the best in this case. It will be shown that the ground water furnishes the most desirable supply.

Works of distribution include: 1st, the distributing system; 2nd, the pumping machinery; and 3rd, the reservoir. The distributing system includes the cast iron pipe lines, their location, computation of size required, etc., also the location of valves and hydrants, and the cost of the system.

A discussion of pumping machinery will be under the following heads: Direct pumping into the mains; kinds of pumps to be used; methods of operation; rate of pumping; size of pumps required; efficiencies and duty of pumping plants; and finally, the cost of plants.

Reservoirs will be discussed in general. The necessary elevation will be determined. It will be shown that

a masonry reservoir on the bluff will be the cheapest and most durable. The form, source of stone, design of walls, and cost will be considered for a concrete reservoir.

A financial comparison of various pumping plants will be made by the method of annual cost of operation. The total cost of Plans 2 and 4 will then be given. Finally, a conclusion will be given.

Four different plans will be discussed in part or completely: Plan 1 is presented as a scheme in which the reservoir is to be elevated high enough to furnish sufficient pressure in case of fire. In Plan 2 the reservoir is at an elevation high enough to serve ordinary pressures, and in case of fire direct pressure from the pumps is to be furnished. In Plan 3 the reservoir is placed high enough to furnish pressure for all small fires. Plan 4 is like Plan 2 except that the First and Fourth Wards and a few lines in the Second and Third Wards are omitted.

---A---

SOURCES OF SUPPLY

Quantity Required.

Population. As future consumption must determine, to some extent, the size and capacity of works, it is important to make an intelligent guess at the future population and probable consumption. To consider the consumption of the present population is very uncertain. The number of taps will be small at first on account of the great confidence people have in private wells. A sewerage system will greatly increase the consumption.

Two schemes for determining future population were made use of. Methods described in "Public Water Supplies," by Turneaure & Russell, on pages 33 and 34. The curves in Fig.1 show the variations in population of different cities before and after a population of 3,000. Fig.2 shows the variations in percentage growth of different cities, by decades. An average of the results of both methods was adopted for our computations.

With the future population of the city as a basis, the development of each ward was considered. The increase in population in a ward depends upon its desirability for residence and business, as well as its general location.

With these factors in mind, the population was distributed to the various wards. Fig.3 shows the relation of various wards to each other with respect to their population in different decades.

Consumption; Ordinary. With no public water supply in the city at present, the present as well as the future, consumption of water must be assumed. In other cities the average consumption varies from 15 to 250 gallons per capita per day, and in the same city may increase as much as 86 gallons per capita per day within ten years. Considering the few needs for water from a public source, the consumption per capita per day is assumed at 30 gallons for the first ten years. However, to allow for increase in consumption, 40 gallons per capita per day is assumed for 1920, and 50 gallons per capita per day is assumed for 1930. The maximum ordinary consumption per hour is assumed at 225% of the average, as it generally varies from 200% to 250%.

Fire. Although the ordinary consumption is variable and uncertain, the fire consumption is even more so. For years the fires may never be so large that they will require more than two or three streams. On the other hand a fire may occur which will require a dozen streams or more.

Kuichling's formula, $2.8\sqrt{\text{Pop. in thousands}}$, was

applied to wards separately and collectively for the number of streams. For the business portion, 200-gallon streams, and in the residence portion, 150-gallon streams, were provided for.

Conclusion. After considering the results of the formula, assumptions were made. It was decided to provide for two fires occurring at the same time as a maximum condition, One fire requiring four 200-gallon streams in the business portion, and the other requiring three 150-gallon streams, together with the maximum hourly consumption. This amounts to 1,550 gallons per minute in 1920, used for the design of pumps; 1,830 gallons per minute in 1930, used for the design of the pipe lines. The results from the formula and assumed values are given in Columns 6 and 7 respectively, in Table I.

Source of Supply.

General. In considering the water supply for the city, three sources presented themselves: First, the Mississippi river; second, artesian wells; and third, shallow wells. The first two sources were not given much consideration, principally for the following reasons:

River.--- Water taken from the river without filtration would at times be very badly polluted and at all times more or less repulsive. If filtered, the cost of filter beds and appliances added to the cost of an intake would be excessive and uneconomical. The location of the reservoir upon the bluff east of the city being so far removed from an economical location of the pumps, constant direct pressure would be necessary, unless a standpipe were erected at some other part of town and the cost of this would also be great. The fluctuations in the stage of the river, from 15 to 18 feet as a maximum, leads to more complicated problems of construction and maintenance. Finally, the people would naturally have a prejudice against river water, although it might be just as pure and potable as their present well water, and this would mean fewer subscriptions and therefore a smaller income to the system.

Artesian Wells.--- At present there are two artesian wells in the city, sunk to depths of 950 and 300 feet res-

pectively. They flow under a small head. The deeper one affords an abundant supply of water, but is strongly charged with mineral salts, which renders it very unsuitable for many purposes, especially for domestic or culinary use.

The most evident constituent is NaCl. Perhaps a still greater objection is to be found in the corrosive effect of Na_2SO_4 and other alkali salts, upon the pipes through which it flows. It is said thata cast iron pipe will be destroyed by it in five or six years. This being the case, such wells are not to be considered as a source of supply.

Wells of about 500 feet in depth furnish good water but the supply is not copious and furthermore, the cost of drilling artesian wells where all but about the first 100 feet is rock, would be very large. Therefore these wells would not be adapted to the requirements of Prairie du Chien.

Ground Water Supply.--- General. Of the sources of supply first mentioned, the one most in favor and the one which we find the most economical, is the shallow well system. The people at present obtain their supply from private driven wells. They are inexpensive and easily sunk, and furnish a comparatively large amount of water. They are sunk only 35 to 50 feet in depth, and con-

sequently in the more thickly settled portions of the city are frequently contaminated by sewage. The city being practically level, drainage is poor, and all such shallow wells are more or less subject to pollution.

Since the city is situated on the sand and gravel deposited in the ancient river bed, the ground water flows readily through the soil from the bluffs. The slope of ground water is determined from the level of the water in wells. Because of flatness of valley and character of soil the percolation will be high. For this reason the ground water supply has always been very abundant.

Present Wells.--- In investigating the ground water supply directly, we observed several of the characteristic wells of the city, determining the size, capacity, depth of the ground water below the surface of the ground, etc. The wells were on a line running approximately east and west, except one well in the First Ward, which is shown in Fig.4. All these wells gave evidence of a bountiful supply and also showed that the ground water level is about 27 to 30 feet below the surface, at low water in the river, in all parts of the city. From these data and the topography of the city, Fig.4 is constructed, indicating a possible condition of the ground water surface. The general slope is from the bluffs on the east and north toward the river on

the south and west. The local slopes of the ground water were not considered, since they are likely to change and calculations based upon them would not be reliable. The general slope being of smaller grade, it is on the side of safety to use it as a basis of computation.

The results in general are rough. The best wells upon which our judgment of the slope is based are the C. B. & Q. Railroad well in the Third Ward, and the well near the College, in the First Ward. The surface of the water in the wells is almost at the same level in both, the level of the water in the former being about 4 feet higher than in the latter. The distance between them being about 8,000 feet, the slope of the groundwater is .5/1000.

Rainfall.--- From Table II. the average annual rainfall is seen to be about 30 inches. From the character of the subsoil we can assume the percolation to be about 50% of the rainfall, which amounts to 261,360,000 gallons per square mile. Also assuming the slope as .0005 and the effective size of sand .8 mm. and porosity 25% minimum for sand and gravel, the rate of flow is 5 gallons per square foot per day. The supply wells being, say, 80 feet deep and the ground water 30 feet below the surface, we have an available water bearing stratum of 50 feet thickness, which means a capacity of 1,320,000 gallons per day per mile in

breadth, that is, with normal slope of ground water. However, as soon as the water in the wells is drawn down the slope becomes greater and the supply increases accordingly. With the bluff area on the east and the large factor of safety in assuming the sand grains .8 mm., the above computations are certainly on the side of safety. Perhaps the most reliable and exact determination of the available supply is that given below, which also indicates that an inexhaustible supply is insured.

Flow.--- The design of the necessary wells is based most largely upon the C. B. & Q. Railroad well. This well is 6-1/3" in diameter, and 40 feet deep, the water level being 27 feet below the ground surface. The yield with a lowering of level of about 1 foot is about 1,500 36-gallon bbls. per day of 10 hours, as given by the engineer, or 129,600 gallons per day of 24 hours. Using a slope of .5/1000 with the above data gives a porosity of 25% for the water bearing stratum, and effective size of sand of .8 mm. (which values were used in the preceding estimate). Using a factor of safety of two on this calculation we obtain the discharges for wells of a given size, depth, and increase of head, as shown in Table III.

Location.--- It was decided to locate the wells

at or near the intersection of Illinois and Bluff streets. The general direction of the slope of ground water is toward the southwest and since there are very few or no houses to the northeast of this point, the danger of pollution from sewage is inappreciable. This is also a central position with respect to the reservoir and the area to be served, and gives a sanitary and economical location. The wells, however, are designed for a depth of 80 feet, which will give a greater rate of flow that the present private wells and will also contribute to their sanitary condition.

Collection.--- Considering the character of the subsurface, driven wells would be the cheapest and most economical means of collecting the water. To prevent the water near the surface from flowing directly into the well, it will be necessary to have a suction pipe within the well tube.

Number of Wells.--- The number of wells required depends upon the rate of pumping and hence will be governed by the system used. Pumping the ordinary consumption for 1920 in a period of 10 hours gives about 350 gallons per minute, or a well capacity of 504,000 gallons per day. To keep the velocity and friction in the suction pipe small, and 8" well with 6" suction is necessary. This well, 80

feet deep, has a capacity of 1,050,000 gallons, which would also be large enough to supply surplus water for fires. If we consider wells sufficiently large or numerous to provide for direct supply for fires, we find that three 8" wells, 80 feet deep, are necessary to discharge the required 1,550 gallons per minute, or 2,220,000 gallons per day. The capacity of each is 1,070,000 gallons per day, but owing to interference we place them 100 feet apart, which gives them a combined discharge of 240% of 1,070,000 gallons, or 2,560,000 gallons, per day. Smaller sizes would give sufficient capacity but their use is prevented by the excessive friction and velocity which would be produced in the suction pipes. Since the larger sizes cost but little more than the smaller ones the former were chosen as more economical.

B
WORKS OF DISTRIBUTION

1.Distributing System.

Pipe Lines. Introduction. ---- In designing the pipe line for Prairie du Chien, the first difficulty was the wide distribution of the population, due to the widely separated wards, and the small number of people per block, particularly in the first ward, necessitating a relatively large amount of pipe for the service given. The water must be carried from the second ward to the first ward through a stretch of about 3,000 feet of pipe having no service pipes whatever. The supply for the fourth ward must likewise pass through about 1,300 feet of pipe across the slough, without house connections. The ordinary service in both these wards is small, but to provide for fires the mains must necessarily be large and therefore expensive. Without these two wards a compact and economical water supply could be designed for the remainder of the city; but since the first and fourth wards are under city rule and the city is to control the system, it is out of the question to neglect any tax-paying portion of the people without their consent. Hence, although the pipe system may seem, and really is, uneconomical as compared with most small cities, we have endeavored to make the best possible arrangement for the city.

Location. By referring to the map of the city, the distributing system as designed for Plan 3 can be seen. The location of pipe lines is the same for all plans except Plan 4, which is the same as far as it goes.

General Problem. The pipe system throughout the second and third wards offers a somewhat complicated problem, but the flow was arrived at by using the following approximations:

Maximum Ordinary Supply on the three principal north and south streets. It was assumed that the same amount of water would not be consumed on all three streets, Church, Minnesota, and Michigan. The consumption upon each street would depend upon the number and character of the residents. In the second ward the consumption on Church street would be 5/12 of the total consumption of the ward. The consumption on the other streets is as given in the following table:

	Ratio	Consumption
Second Ward--		Gals.per Min.
Church,	5/12	76
Minnesota,	5/12	76
Michigan,	2/12	32
Third Ward--		
Church,	4/12	78
Minnesota,	5/12	96
Michigan,	3/12	58

Three 200-gallon fire streams are assumed as a maximum on any one street.

Conditions governing the consumption on Main street and Church street are somewhat similar, and calculations based upon Minnesota will be safe for Church. The maximum consumption for Minnesota street in the Second ward is 676 gallons per minute, one half of which is assumed to flow in at Bluff and one half at Webster; in the third ward, 696 gallons per minute, one half flowing in at Bluff street and one half at Perry.

It was considered more nearly accurate for Michigan street, to assume the maximum flow equal to the maximum supply for Minnesota, plus the maximum ordinary on Michigan street, or 338 + 32 = 370 gallons per minute for the second ward; and 350 + 58 = 408 gallons per minute for the third ward.

Assumption. Following are some of the constants used in the design of the pipe line:

Hose with a 1" nozzle.

Hose 300 feet in length sufficient for first and fourth wards.

Hose 600 feet in length sufficient for second and third wards.

150 gallon stream for fire in residence portions of city.

200 gallon stream for fire in business districts.

Table showing actual pressures for given streams and lengths of hose:

Size of Stream	Height of Stream	Length of Hose	Pressure at Hydrant Feet	Pressure at Hydrant Pounds
150 gals.	45'	300'	99	43
150 "	45'	600'	133	57.5
200 "	69.8'	600'	235.6	102.0

Assumed Hydrant Pressures:

1st and 4th Wards,	118'	50#
2nd and 3rd wards, business districts,	208'	90#
2nd and 3rd wards, residence "	148'	60#

Calculation. From the above assumptions and constants and the table showing consumption for the different wards, Table IV. is constructed. It shows the result of designing the pipe line for economic velocities when there is constant fire pressure from the reservoir.

With this system it is obvious that the friction in the pipes is very small and consequently the cost of pumping will be diminished. Also the reservoir, which is designed to be located on the bluff, could be placed at a lower elevation and hence made more conveniently accessible. This latter consideration, however, is of little moment,

since a few, or even several, feet difference in elevation of the reservoir does not appreciably affect the length of pipe required nor the economy of its construction. But the consideration which outweighs all others is the first cost, and from this point of view the system requiring large pipes for economic velocities is not advisable if smaller pipes can be used by some other method. The cost far exceeds that of the system designed from practical velocities, as will be observed in the final estimates of the different systems.

By practical velocities we mean velocities not exceeding eight or ten feet per second in case of fire or of extreme maximum consumption. The high velocities are ordinarily of short duration, perhaps lasting not over two hours in any instance. They therefore offer no serious objection further than that the pumps are more heavily taxed for the time.

Table V. gives the equivalent sizes of pipe and the resulting friction under different conditions. Only two essentially different schemes of sizes are given.

In the first the sizes of pipe are the same as in the economic system excepting that from the intersection of Church and Bluff to the reservoir it is reduced from 16" to 10". This system is considered only with maximum con-

sumption for 1930.

In the second scheme all pipes are made 6" excepting from the intersection of Church and Bluff to the pump, which is 10", and from Lewis to Church and well to the reservoir, which is 8". This system is considered for maximum consumption up to 1920 and also to 1930, and for ordinary consumption up to 1930. Friction for 8" and 12" pipe from pump to reservoir is also given in Table V.

Conclusion. The first system permits of considerable hydrant pressure from the reservoir without excessive elevation and will provide for nearly all fires, at least up to 1920; then, if necessary, direct pumping could be employed for fire pressure. The latter system is suitable for providing reservoir pressure for small fires up to 1920, using direct pressure in cases of necessity.

If after 1920 the reservoir were to supply the ordinary consumption of 600 gallons per minute only, then the 8" pipe could be used without extreme elevation of the reservoir, since the ordinary hydrant pressure in residence districts is 60' and not more than 75' in business districts, and the loss of head in friction from reservoir to pumps is only 37'. But although an 8" pipe would be serviceable for ordinary consumption up to 1930, it would not make the reservoir storage available for fires of any importance in the

outskirts of the city.

Location of Valves and Hydrants. Valves are placed so that sections of the system can be shut off without closing the whole system. Their positions are shown on the map.

Only hydrants of the two-way type are considered in the design. They are placed on corners opposite large buildings, on vacant corners if possible. They are so spaced that they will give the required number of streams at any point along the pipe lines, so that no hose will be longer than 600' in the second and third wards, and 300 feet in the first ward.

Cost. Cost per lineal foot of pipe laid, per hydrant, and per valve was taken from current contract prices. The cost of the system for Plans 2, 3, and 4 are given in Table X. After the sizes of pipes and head required for Plan I. had been computed, it was apparent that the system would not be economical. It would necessitate a very high cost of installation for large pipes, and a great annual expense in pumping all the water under a high pressure.

2. Pumping Machinery.

Direct Pumping. Pumping directly into the mains

at all times will not be considered for various reasons. The plant would have to be operated at a small fraction of full load 24 hours a day. The cost of attendance would be two or three times as much as when pumping to a reservoir. The efficiency of the plant being lower, due to small load, operating expenses would be increased. Considering only these losses, it will take but a short time to more than pay for a reservoir from the saving in expenses. It can give a supply of water in case of accident to the pumping plant. In all plans except Plan I it will be necessary to pump directly into the mains in case of a large or even a small fire. When direct pressure from the pump is furnished the pipe leading to the reservoir must be shut off. With a reservoir the pressure in the mains will be constant.

Kind of Pump. Considering the fact that the system is a small one, pumping will only be required a fractional part of the day. The high efficiency of power pumps and the variety of methods of operating them, make them very desirable in small systems. For this reason only power pumps will be considered.

Methods of Operation. There are various methods of operating pumps. They may be operated by steam, gasoline engines, motors, or combinations. Each method has its

advantages and disadvantages. Motors have a low first cost when electricity is furnished by an electric light company, but operation is very expensive. A plant large enough to furnish fire pressures must be operated at a fraction of its capacity. For such operation the steam engine is best adapted. On the other hand, electric generators and motors are built with as high efficiencies at 1/4 load as at full load. For a small load, which need only be carried 8 or 9 hours a day, the electric motor is evidently the most convenient. However, a motor can only be used for a part of the capacity required, because the power available from the light company is limited. The only attention required with a motor is oiling, inspecting, and cleaning of the machine once a day, which may be done by the superintendent of the works. A float in the reservoir may be used to operate the motor, and thus keep the reservoir filled within certain limits. A gasoline engine is very useful in case of fire, because it requires but a moment to start it. A licensed engineer is not required to operate it.

Rate. Since a reservoir is used for ordinary service, the pumps can be operated at any constant rate a certain number of hours each day.

At 400 gals.per min. requires 4 hours to pump 97,000 gals.
" 400 " " " " 5 " " " 112,000 "

At 400 gals.per min. requires 8-1/3 hrs.to pump 200,000 gals.
" 200 " " " " 8 " " " 97,000 "
" 200 " " " " 9-1/3 " " " 112,000 "

Size of Pumps. For an economic system which could be depended upon for at least 15 years, requires 2 pumps of a total capacity of about 1600 gallons per minute. For this purpose two triplex pumps were chosen, one of 600 gallons per minute capacity, and the other of 1,000 gallon capacity. The small pump may be used most of the time for ordinary service, while the larger one should be used occasionally to make sure that it is in good order when needed.

In Plan 4 smaller pumping capacity may be provided for. For this Plan, 2 pumps of 400 and 600 gallon capacities, respectively, were chosen.

Efficiencies. For various schemes of operation efficiency diagrams were drawn, Figures 6, 7, 8, and 9. From these diagrams the indicated horse power (I.HP.) required, may easily be determined. It is equal to the theoretical HP. divided by the efficiency. Table VI. gives the theoretical HP. required for various rates of pumping to different heights. It also gives the I.HP. required.

The duty is the ratio of foot pounds of work done to energy expended in heat units. From the efficiencies

determined in the diagrams, the duty of a pumping plant operated by steam would be 6% x 64% x 778,000,000 = 30,000,000

Cost. Costs of the pumping plants as designed for the various methods of operation are tabulated in Table VII.

3. Reservoirs.

General. A reservoir should not only serve as an equalizer of pressure, but should have enough storage capacity to provide for at least one day's consumption. If the reservoir has a capacity of 200,000 gallons, it will supply the average daily consumption required in 1920.

For various reasons it was decided to locate the storage tank or reservoir upon the bluff east of the city. It is found that it is cheaper, more easily constructed, less unsightly, and safer than a standpipe built in the central part of the city. The soil being soft and treacherous, it would require a large expense for a foundation for a standpipe even of small size, and it is not economical to build a large standpipe of a size equivalent to that which is available on the bluff. The cost of the steel structure itself is large and excessive compared with the cost of a reservoir, of whatever material it may be constructed, on account of the different shape due to increased height. A reservoir built upon the bluff can be placed at almost any

elevation below the summit with little difference in cost.

Elevation of Reservoir. As has already been shown the bluff is not sufficiently high to give the pressure necessary for large fires. The reservoir will accordingly be placed either high enough for ordinary service, or high enough to give sufficient pressure for single small fires, up to 1920. The necessary elevations for the second case are worked out approximately upon assumption of fire supply in different parts of town, as follows:

	Length	Size	Gallons per Min.	Friction	Total
1st Ward to Reservoir, 3 150-gal.	4510'	10"	800	22'.5	
	7500'	8.3"	500	37.5	
			Hydrant,	118.0	178'
4th Ward to Reservoir, 3 150-gal.	5000'	10"	800	25'	
	4415'	7.3	433	42	
			Hydrant,	118	185'
3rd Ward, (near church) 4 150-gal.	2000'	9.3	722	18'	
	4510'	10"	900	27.5	
			Hydrant,	148.0	193'.5
2nd Ward at High School, 4 150-gal.	3000'	10.2"	700	10'.5	
	4510'	10"	1000	34.5	
			Hydrant,	148	193'
2nd and 3rd Ward at Lighting Station, 4 200-gal.	1950'	10"	900	5'.7	
	4700'	10"	1100	44.8	
			Hydrant,	208.0	258'.5

For Plan 3 an average of 190 feet above Illinois street at Bluff will be taken as the elevation of the top of the reservoir.

For Plan 2 the elevation required is 125 feet. The average head against which the pumps must operate is about 160 feet in Plan 2, and in Plan 3 it is about 200 feet.

Steel tanks. A steel tank was at first considered but this, unless placed at the top of the bluff, would require a large amount of excavation. To afford a storage of about 200,000 gallons, or one day's ordinary consumption for 1920, would require a tank about 40 feet in diameter and 20 feet high. Considerable excavation and labor would be necessary to prepare the foundation for such a tank, even if it were placed on the summit of the hill, and the cost of a cover would be large. For several years to come the tank would not, perhaps, be taxed to its full capacity and little circulation of water would result; and being located in a cold, exposed position, it might be necessary to provide against the action of frost. This, however, is not a serious objection, since there would be little possibility of harm being done by accumulations of ice in a tank so constructed.

Masonry Reservoir. Form and Size.--- Since it is not necessary to place the reservoir at the top to provide for small fires, the pressure against which the pumps work can be reduced by placing the reservoir on the side of the bluff. In this event it was proposed to construct a reservoir of masonry and concrete, the dimensions to be 60' x 30' x 15', with the long axis parallel to the side of the hill. The excavation for a reservoir of this shape will not be much more than for a round tank of equivalent capacity. The slope of the bluff on the north side next to the road is very uniform and makes an angle of about 30° with the horizontal. A reservoir of the size given, with a horizontal bottom, has a capacity of about 200,000 gallons. With the bottom sloping toward the bluff at a depth of 10 feet at the inner well, as shown in Fig.5, the capacity is increased to about 260,000 gallons.

Source of Material.---It is proposed to blast out the site for the reservoir and use the stone obtained in this manner for a wall on the front side and for that part of the ends which is open. The wall will then be faced with concrete and lined with neat Portland cement to make it water tight. The natural rock will form the back wall and part of the ends and will simply require a pointing up or grouting and lining of cement. The bottom can be

similarly treated. A cover can be easily and cheaply constructed for a reservoir of this shape and size, which might be a considerable item for the round tank. Such a reservoir if well constructed will be practically permanent and will require little expenditure for repairs.

Design.--- Following is computation of thickness of wall required:

a = thickness of wall at top = 1 foot.

b = height of reservoir = 15 feet

g = specific gravity of masonry = 2.5

$$l = \sqrt{\frac{5}{4} + \frac{h^2}{g}} - \frac{a}{2}$$

$$= \sqrt{1.25 + 90} - .5 = 9.05$$, width of bottom of wall.

Cost.--- It was found that it is slightly cheaper to blast out sufficient rock to give the bottom of the reservoir and front wall a natural rock foundation than it is to make the excavation narrower and build up a masonry shelf on the front side. The former will also be safer. The rock is a limestone, not very hard, and cost of blasting and cleaning up is estimated from Gillette's roads ~~and~~ at 40¢ per cubic yard. The cost of masonry and concrete is taken at $7.00 per cubic yard. (30' base).

Cost of reservoir of 200,000 gals. capacity:

900 cu.yd. excavation,	@40¢	=	$ 360.00
205 " masonry,	@$7.00	=	1,435.00
3,500 B.M. Timber,	@$20.00	=	70.00
Miscellaneous,			35.00
Total cost, - - - - - - - - - - - - - -			$1,900.00

Cost of reservoir of 260,000 gal.capacity,-- 2,050.00

Annual Cost of Operation.

The economic construction will depend upon the sum of the first cost, the cost of operation and repairs, and the cost of renewals. Various plants may be compared financially by comparing their annual costs, which are the sum of the interest on the cost of installation, annual cost of operation, annual cost of maintenance and repairs, and the annual debit to sinking fund.

In order to determine the annual cost of operation, various units were assumed. The cost of each kilowatt hour, 5¢; gasoline at 0¢ per gallon; and coal at $4.00 per ton of 2,240 lbs. Average annual cost of operation for 20 years was assumed to be the same as that for the year 1910. Rate of pumping was assumed at 200 gallons per minute, against a total head of 170 feet. The amount of gasoline was assumed at .15 gallon per I.H.P. per hour. From the efficiencies the duty of the steam plant is 30,000,000, and the coal required is 6.6 lbs. per H.P. per hour.

Total Cost.

The financial comparison made in Table VII. shows the use of gasoline engines to be the most economical method. No financial comparison was made for Plan III. because the relative economy of the different methods of operation would be practically the same, at a greater cost of operation as well as first cost.

In Plan IV. the gasoline engines are also the most economical. However, as this scheme is only presented in lieu of something better, having a low first cost, it would be better to use an electric motor with one gasoline engine, or two motors if 75 H.P. can be furnished by the light company in case of fire. This Plan 4 cuts out pipe lines in the first and fourth wards; also Michigan, Main, Illinois, and parts of Louis, Bluff, Webster and Perry streets.

	Cost of Plan 2.	Plan 4.
Pipe lines, complete,	$23,614	$12,790
Pumping Plant,	16,000	6,900
Small reservoir,		1,900
Large reservoir,	2,050	
Engineering, at 5%,	2,080	2,160
Total, - - - - - - - -	$43,744	$23,750

Conclusion.

Although Plan 4 is the cheapest it is not the most desirable since two wards are thereby left without fire protection. A minor objection would be the cost of extending Plan 4 in the future. If it were later desired to make the system equal to the system of Plan 2, the whole cost would exceed that of originally installing the system according to Plan 2.

We recommend Plan 2 as the best system. Pipe lines can be added when needed. Those laid out on the map for Plan 2 supply water only on the principal streets. The pipe lines on Webster, Perry and Broadway will prevent the occurrence of too many dead ends and secure a better circulation.

The cost of Plan 2 is less than any other system in Wisconsin of about the same size.

Cost of system for Antigo with 1 mile less of pipe is $60,000
" " " " Kenosha " 1/2 " " " " " $30,000
(No pumps.)

Cost of system for Beaver Dam with 2 miles more pipe is $125,000.

Table I.

POPULATION, CONSUMPTION.

Ward	Population	%	Gallons					
			Average per min.	225%	Fire	Assumed Fire	Maximum	Average per year
				(First Year)				
1	626	19.4	13.2	30	333	450		
2	1049	32.4	21.9	49	573	600		
3	1211	37.5	25.4	57	620	600		
4	346	10.7	7.2	16	250	450		
All	3232	100.0	67.5	152	907	1000	1152	
2&3	2260	70.0	47.3	108	800	800	908	24,900,000
				1910				
1	675	18	14.0	32	354	450		
2	1200	32	25.0	56	527	600		
3	1500	40	31.2	70	538	600		
4	375	10	7.8	18	263	450		
All	3750	100	78.0	176	1087	1250	1426	40,900,000
2&3	2700	72	56.2	127	920	800	927	
				1920				
1	925	18.5	25.7	57	405	450		
2	1550	31.0	43.2	97	525	600		
3	1925	38.5	53.5	120	600	600		
4	600	12.0	16.6	38	326	450		
All	5000	100.0	130.0	312	1250	1250	1562	73,100,000
2&3	3475	70.0	96.7	213	896	800	1018	
				1930				
1	1375	18	46	105	492	450		
2	2300	31	81	182	637	600		
3	2925	39	102	228	720	600		
4	900	12	31	70	400	450		
All	7500	100	260	585	1350	1250	1835	136,800,000
2&3	5225	70	182	410	1280	800	1210	

Table II.

RAINFALL IN INCHES, FOR PRAIRIE DU CHIEN

	1891	1892	1893	1894
January	1.81	1.86	1.81	0.79
February,	1.05	1.21	1.00	0.66
March,	2.44	1.13	1.97	1.99
April,	1.11	4.03	3.07	2.51
May,	1.65	8.26	3.86	----
June,	2.95	13.53	2.45	2.64
July,	1.76	2.82	5.69	0.04
August,	2.32	3.37	2.61	1.13
September,	1.73	1.96	1.40	3.65
October,	1.82	1.26	3.00	2.57
November,	0.96	1.00	1.18	1.50
December,	2.82	1.47	1.41	----
Total,	22.42	41.90	29.45	-----

Average Annual Rainfall, 30.31".

Table III.

CAPACITY OF WELLS, GALLONS PER DAY.

- - - - - - - - - - - - -

60' Wells

Diameter	H - h 4	5	6	7
2"	332,000	408,000	480,000	550,000
4"	352,000	432,000	509,000	584,000
6"	364,000	448,000	526,000	603,000
8"	392,000	470,000	544,000	610,000

80' Wells

Diameter	H - h 4	5	6	7
2"	576,000	704,000	836,000	966,000
4"	610,000	746,000	886,000	1024,000
6"	630,000	794,000	916,000	1056,000
8"	680,000	814,000	944,000	1070,000

Table IV.

Economic Velocity System for Plan I.

Location	From	To	Max. Cons. Gals., Min.	Ratio Max.: Ord.	Economic Velocity	Actual Size	Eq'vl't Size
4th Ward	Extreme End	Main	520	7.3	3'.6	8"	8"
Bluff	Lewis	Church	900	13.0	4.2	8"	9.4"
(Branch)	"	"				6"	
1st Ward	3rd & Parish	2nd & Broadway	520	7.3	3.5	6"	7.7"
"	"	"	520	7.3	3.5	6"	
Church	Broadway	Webster	520	7.3	3.3	8"	
"	Webster	Bluff	760	4.2	4.8	8"	
"	Perry	"	350	7.2	3.9	6"	
Minn.	Webster	"	340	8.9	3.9	6"	
"	Perry	"	350	7.2	3.9	6"	
Mich.	Webster	"	370	11.5	4.2	6"	
"	Perry	"	410	7.0	4.6	6"	
Bluff	Michigan	Reservoir	1840	3.1	3.0	16"	
"	"	Church	1066	2.55	4.0	12"	

--Friction Between Different Points--

From	To	Max.Cons. Gals., Min.	Equiv. Size.	Length	Pipe Friction
College	Webster	560	7".9	4790'	40'.7
Web.& Ch.	Michigan	1160	10.6	2670	20.1
4th Ward	"	520	8.5	5170	27.40
Perry & Ch.	"	600	9.3	2990	12.80
Reservoir	Michigan	1840	16.0	4560	10.00

Pipe Friction from Reservoir To		Hydrant Pressure	Total
College,	70'.8	118'	188'.8
Webster & Church,	30.1	148.0	178.1
Perry &, Church,	22.8	148.0	170.8
4th Ward,	37.4	118.0	155.4
Prairie,	15	208	223.0

Table V.

Plan 3.

For Maximum Fire Consumption.

From	To	Equivalent Size	Pipe Friction 1930	Pipe Friction 1920	Max. Ord. Friction 1930	Hydrant Head Required
College	Webster	7.9"	40.7'			118'
Webster	Pump	10.6	20.1			148
4th Ward	"	8.3	33.3			118
Perry	"	9.2	20.0			148
Reservoir	"	10.0	91.0			208
Prairie & Bluff	"					299

Plan 2.

College	Webster	6.4"	108'	86'	6.3'
Webster	Pump	9.3	44	39	3.9
4th Ward	"	6.0			
" "	"	7.7	131	116	5.6
" "	"	10.0			
" "	"	10.0			
Perry	"	9.2	20	15	
Reservoir	"	10.0	91	66	13.2
"	"	12.0	39		
"	"	8.0			36.8

Table VI.

REQUIRED TABLE OF HORSE POWER.

Gals. Per Min.	Head	Theoretical HP. 100%	Efficiency, 64%	Engine H.P.		Motor H. P.	
				44%	23.5%	85% of 44%	80% of 235%
200	170′	8.6	13.4	19.5	36.5	16.5	29.2
	220	11.1	17.3	25.2	47.2	21.4	37.7
400	170	17.2	26.8	39.0	73.0	33.0	58.3
	220	22.3	34.7	50.6	95.0	43.0	76.0
600	170	25.8	40.3	58.7	110.0	49.7	88.2
	220	33.4	53.8				
	300	45.5	71.0	103.0		87.5	
800	300	60.7	94.8				
950	300	73.0	112.0				
1250	300	94.8	148.0				
160	170	6.9			29.0		
	220	8.4			35.8		

Table VII.

COST OF OPERATING PLANT.

Plan 2.

Cost of:

70 HP. Motor,	$1,250	$1,250		
110 HP. Steam engine,	1,800		$1,800	
110 HP. Boiler,	2,000			
Pump house,	2,000	1,500	2,000	$2,000
Pump,	4,500	4,500	4,500	4,500
3 Wells,	500	500	500	500
110 HP. Gasoline Engine,		5,500		5,500
70 " " "				3,500
70 " Steam Engine,			1,100	
2 90 HP. Boilers,			3,600	
Total,	$12,050	$13,250	$13,500	$16,000

Plan 4.

30 HP. Motor,	$550		$ 550		
45 " "	810				
Pumps,	3,500	$3,500	3,500	$3,500	$3,500
Pump house,	500	2,000	700	800	700
Wells,	200	200	200	200	200
25 HP. Steam Engine,		500			
40 " " "		800			
40 " Gasoline Engine,			2,500	2,500	2,500
30 " " "				2,000	
2 Boilers,		3,000			
Total,-------	$5,560	$10000	$7,350	$9,000	$6,900

Table VIII.

FINANCIAL COMPARISON.

Plan 2.

Estimated Cost of Operation

System	Engin'rs	Oil Repairs	Fuel	Total	Saving
Motors,	$ 200	$ 50	$3,580	$3,830	$1,410
Gasoline,	400	140	590	1,130	4,110
Steam,	1,440	150	520	2,110	3,130
Motor and gasoline,	300	150	3,590	4,080	1,160
Motor and steam,	1,440	175	3,600	5,240	0,000

Amount of Investment Warranted by Saving

	First Cost	Cost of Operation	Saving Per Year	Saving Capitalized at 6%
Motors,	$8,525	$3,830	$1,410	$23,700
Gasoline,	16,000	1,130	4,110	69,000
Steam	13,500	2,110	3,130	52,000
Motor & Gasoline,	13,250	4,030	1,160	17,000
Motor & Steam,	12,050	5,240	0,000	

Financial Comparison

	5% on Cost	Cost of Operation	Sinking Fund	Total Cost Per Annum.
Motors,	$426	$3,830	$340	$4,596
Gasoline,	800	1,130	640	2,570
Steam,	675	2,110	540	3,225
Motor & Gasoline,	663	4,080	530	5,273
Motor & Steam	602	5,240	482	6,324

Table IX.

FINANCIAL COMPARISON.

Plan 4.

Estimated Cost of Operation

System	Engineers.	Oil Repairs	Fuel	Total	Saving
Motors,	$ 100	$ 25	$1,350	$1,475	$ 125
Gasoline,	200	100	380	680	920
Steam	1,000	100	332	1,432	168
Motor & Gasoline,	200	50	1,350	1,600	---

Amount of Investment Warranted by Saving

	First Cost	Cost of Operation	Saving, 1 Year	Saving, at 6%.
Motors,	$5,560	$1,475	$125	$2,080
Gasoline,	8,900	680	920	15,300
Steam,	10,000	1,432	168	2,800
Motor & Gasoline	7,350	1,600	---	-----

Financial Comparison

	5% on Cost	Cost of Operation	10% Sinking Fund	Total Per Annum
Motor,	$273	$1,475	$556	$2,304
Gasoline,	446	680	890	2,016
Steam,	500	1,432	1,000	2,932
Motor & Gasoline,	363	1,600	735	2,698

Table X.

PIPE LINES.

On	Plan 2 Length	Plan 2 Diameter	Plan 2 Unit Cost	Plan 2 Cost	Plan 3 Diameter	Plan 3 Unit Cost	Plan 3 Cost	Plan 4 Diameter	Plan 4 Length	Plan 4 Cost
Reservoir to well,	4180′	8"	$1.00	$4180	10"		$5225	8"	4180′	$4180
Bluff,	1140	10	1.25	1425	10"		1425	10"	1140	1425
Bluff,	700	8"	1.00	700	8"		700	8"	400	400
Church,	4140	6"	.58	2400	8"	1.00	4140	6"	4140	2400
Minn.,	4140	6"		2400	6"		2400	6"	4140	2400
Mich.,	4140	6"		2400	6"		2400			
Ill.,	800	6"		464	6"		464			
Main,	500	6"		290	8"	1.00	500			
Louis,	560	6"		326	6"		326		350	203
Prairie,	900	6"		522	6"		522	6"	500	290
Perry,	760	6"		418	6"		418	6"	380	209
Webster,	760	6"		418	6"		418	6"	380	209
Total,	22720′									
	No.					No.		No.		
Hydrants	32			960			960	26	26	780
Valves,	3-10"			72	10"	6	144	2-10"	2	48
	3-8"			54	8"	2	54	3- 8"	3	54
	13-6"			216	6"	17	204	12-6"	12	192
Total,				$17317			$20890			$12790

(Forward to p. 44)

Table X., Continued.

PIPE LINES.

		Plan 2			Plan 3		
		First Ward					
On	Length	Diam.	Unit Cost	Cost	Diam.	Unit Cost	Cost
Church,	3430′	6"	$.58	$2650	8"	$1.00	$3430
2nd,	1060	6"			6"	.58	615
3rd,	1060	6"		615	6"		615
Broadway,	300	6"		174	6"		174
Parish,	300	6"		174	6"		174
Total,	6150′						
Hydrants,	10			300			300
Valves,	4			48			48
Total,				$3961			$5356
		Second Ward					
Marsh,	650′	6"	.58	378	8"	1.00	650
River,	500	6"	1.00	500	8"	1.25	625
Ward,	2200	6"	.58	1276	6"	.58	1276
	3350′						
Hydrants,	6			180			180
Valves,	1			12			16
Total,				$2346			$2747
" First Ward,				3961			5356
" From p. 43,				17317			20890
Grand Total,				$23614			$28993

Fig. 1.

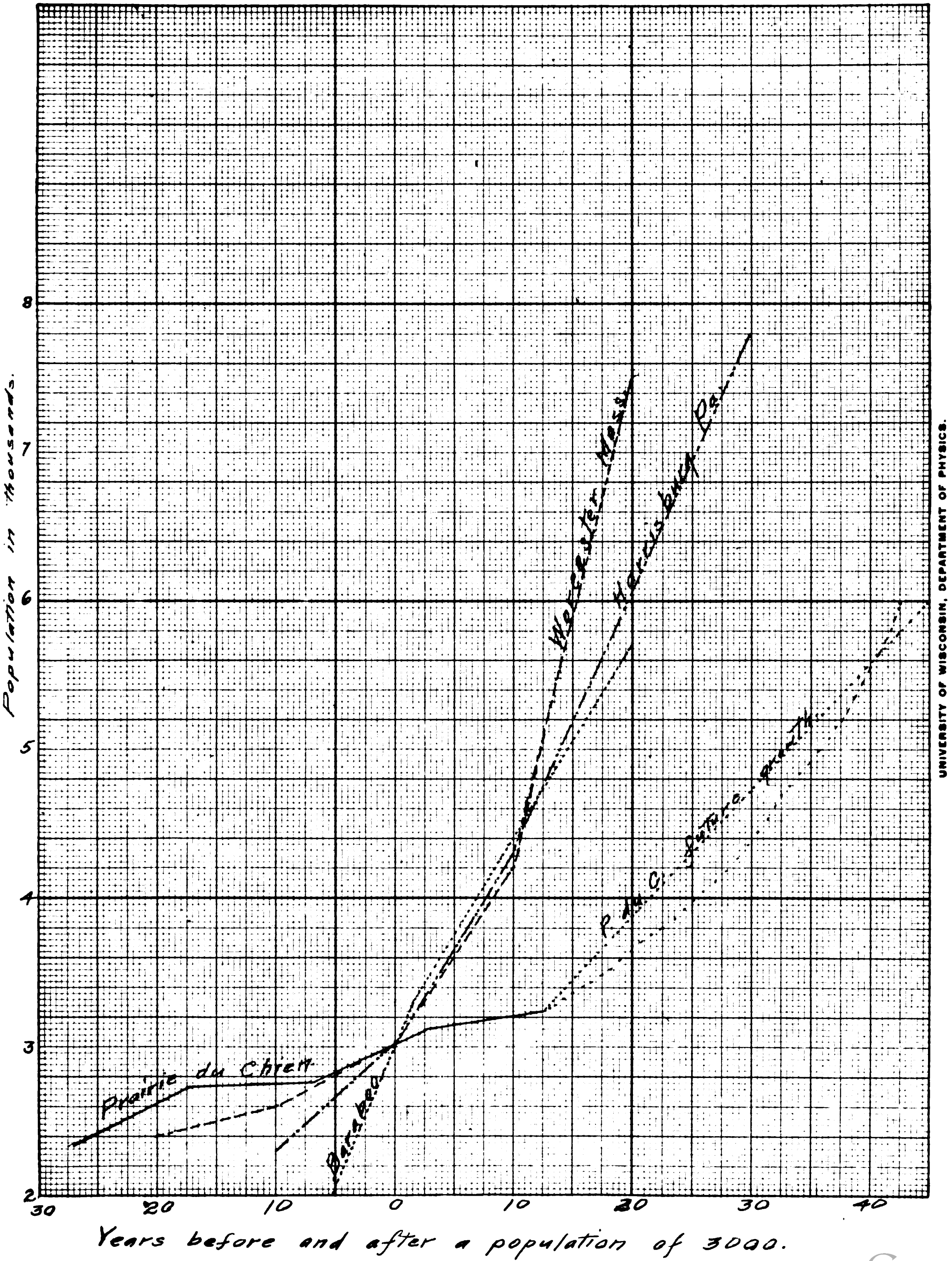
Population in thousands.
8
7
6
5
4
3
2
30
20
10
0
10
20
30
40
Prairie du Chien
Baraboo
Webster Mass.
Harrisburg Pa.
P. du C. future growth
Years before and after a population of 3000.
UNIVERSITY OF WISCONSIN, DEPARTMENT OF PHYSICS.

Fig. 2

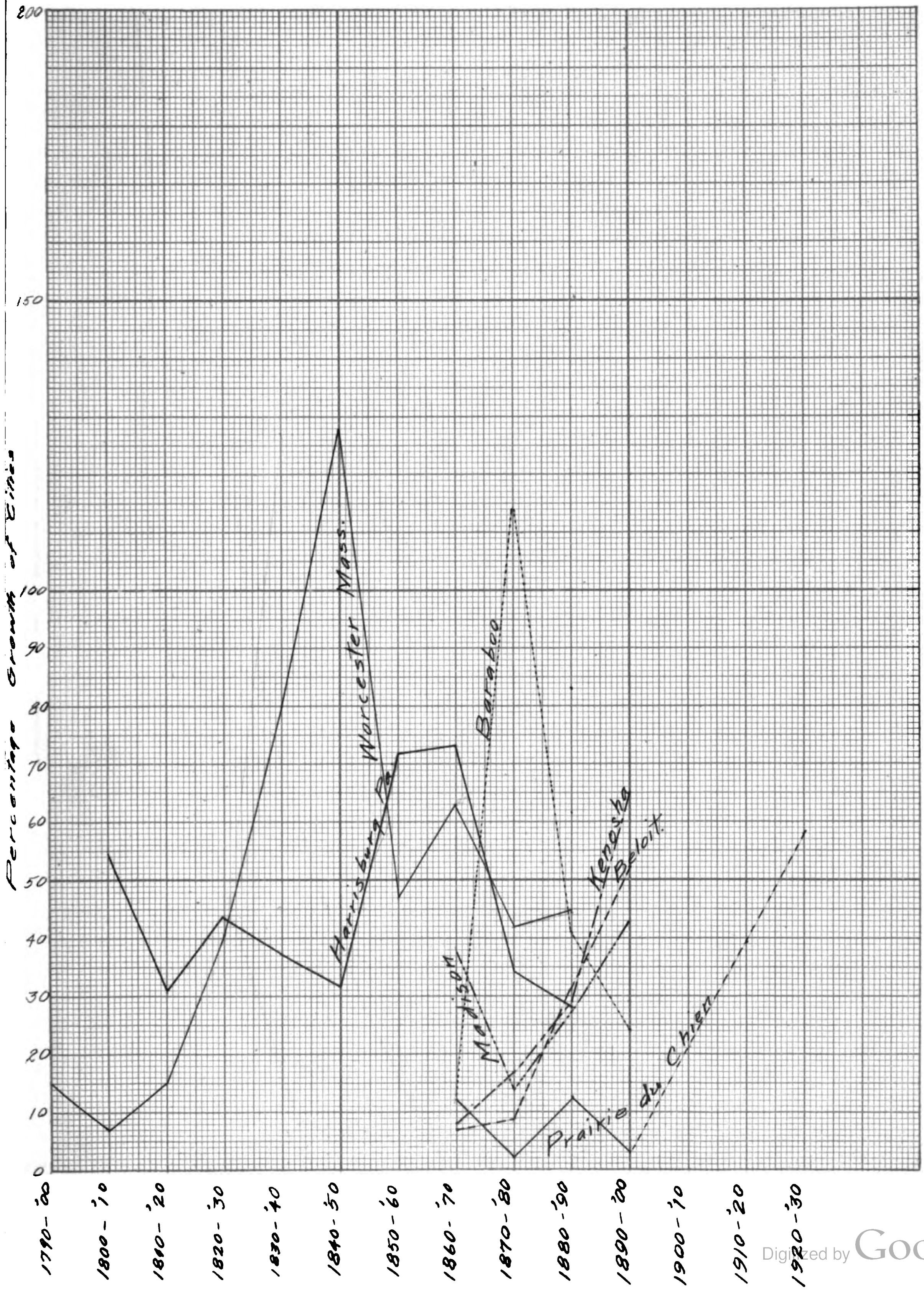

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Fig. 3.

Population of Wards in Thousands.

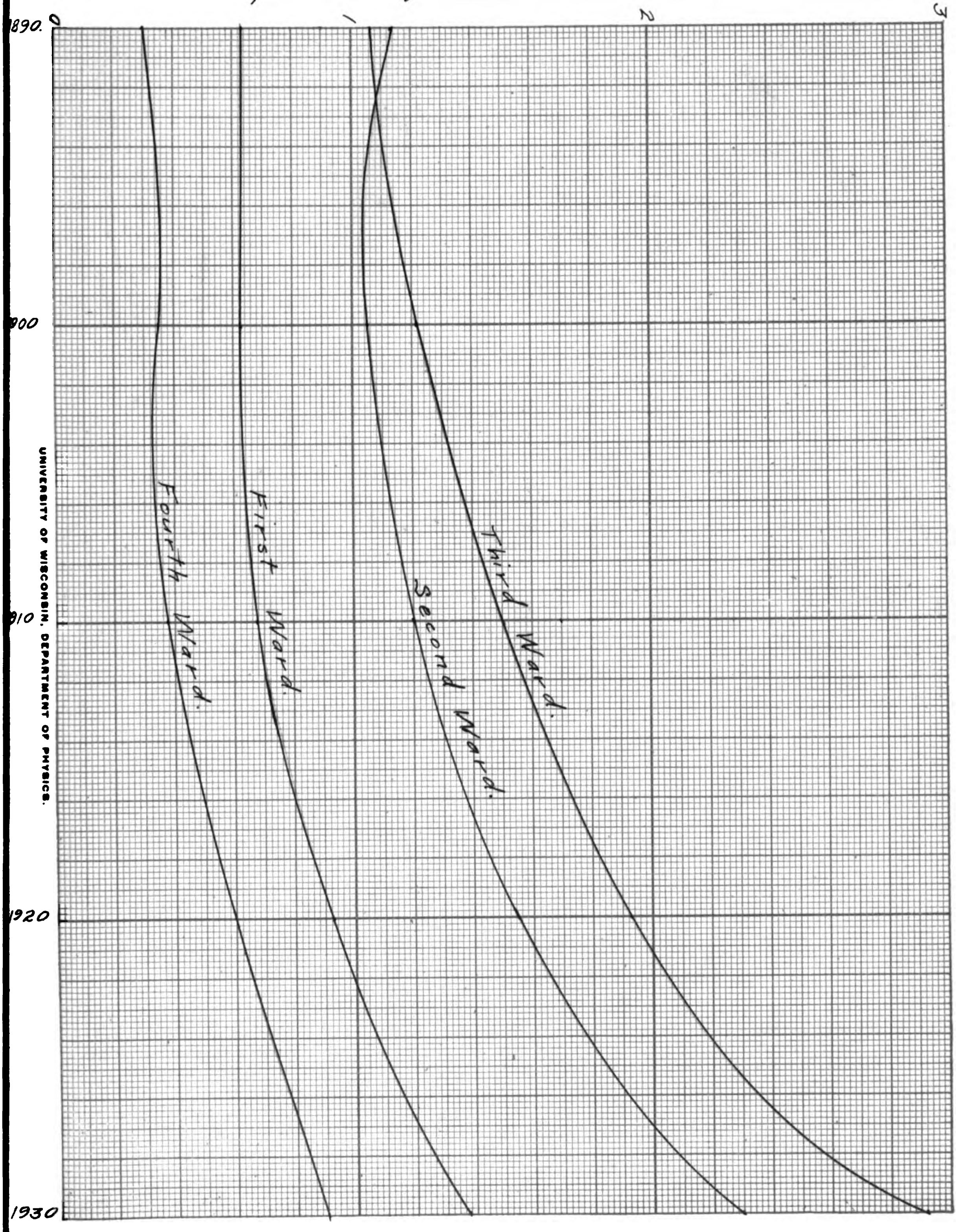

Fig 4.

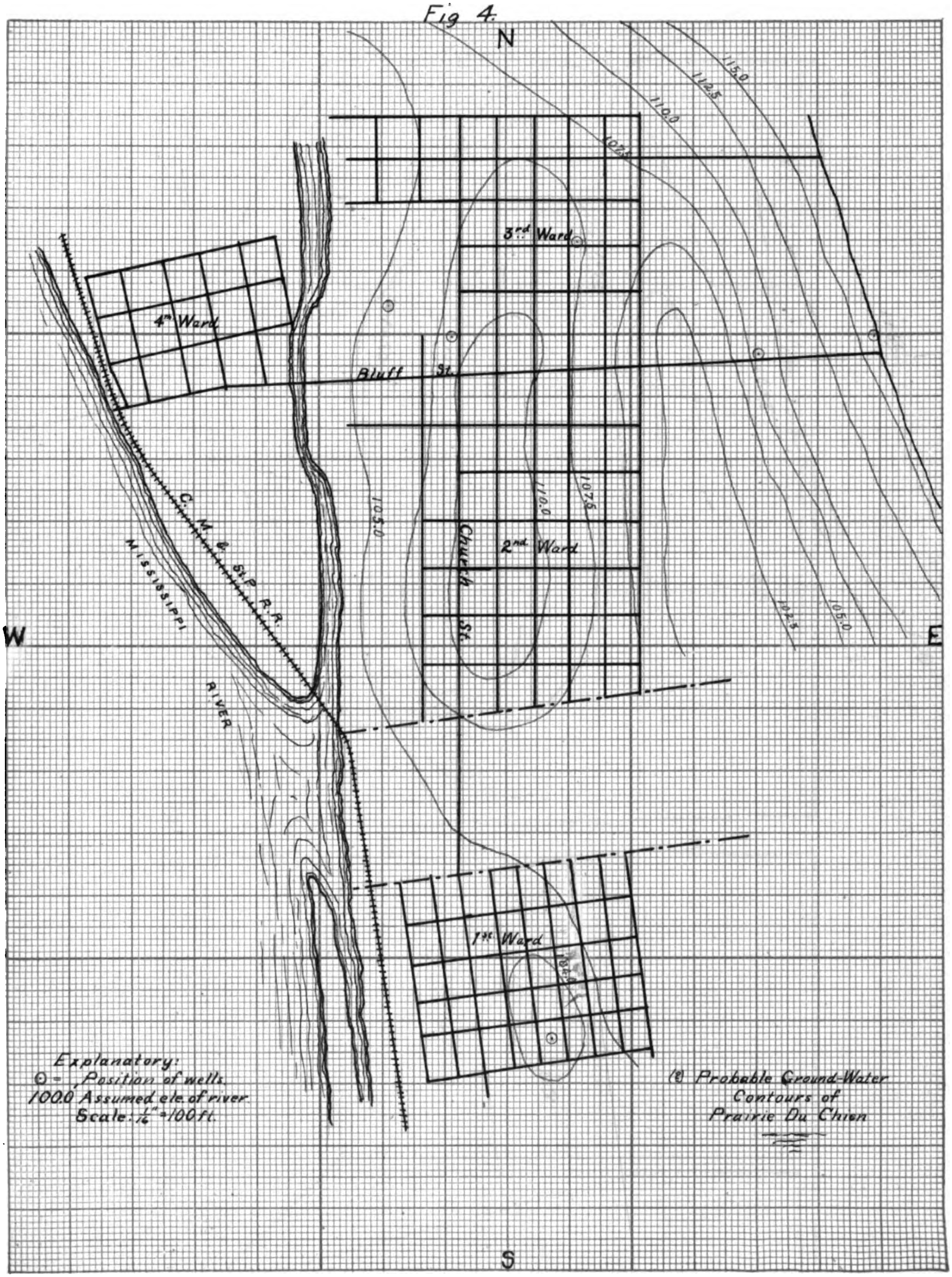

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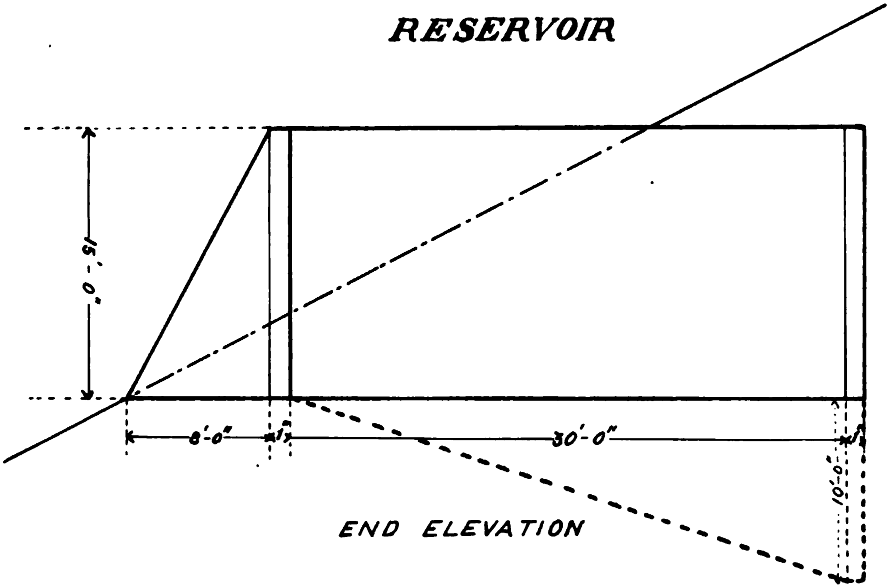
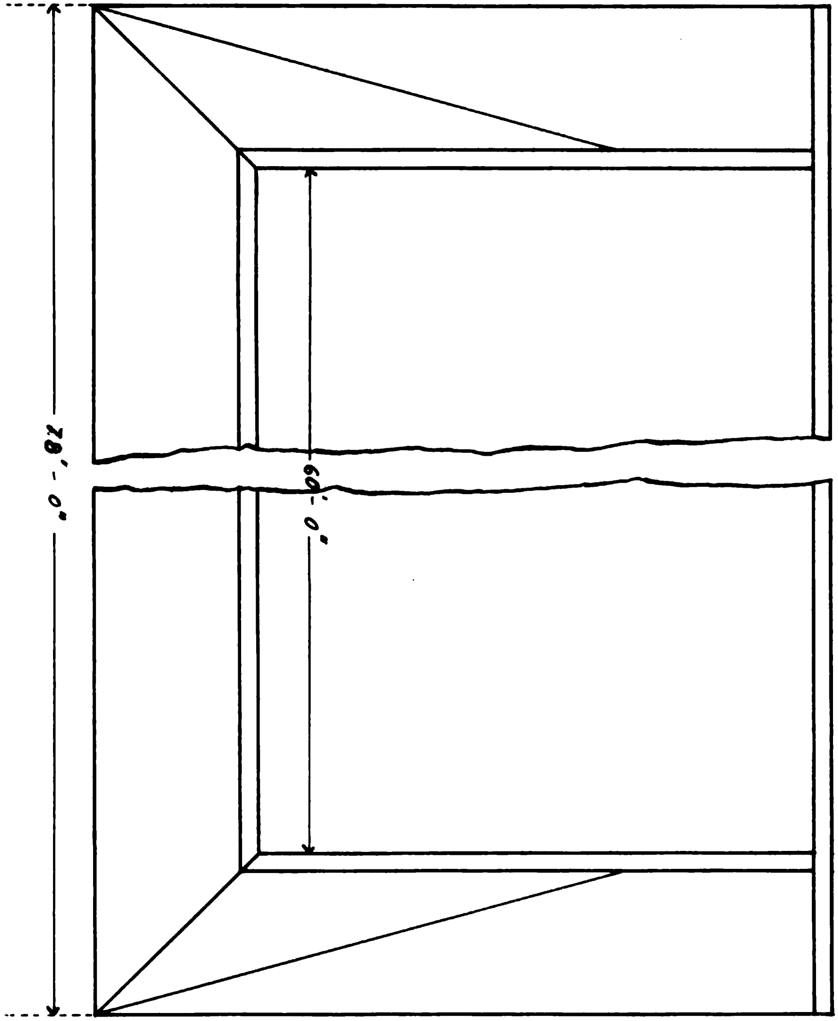
Fig. 5.

RESERVOIR



END ELEVATION



PLAN

Fig. 1.

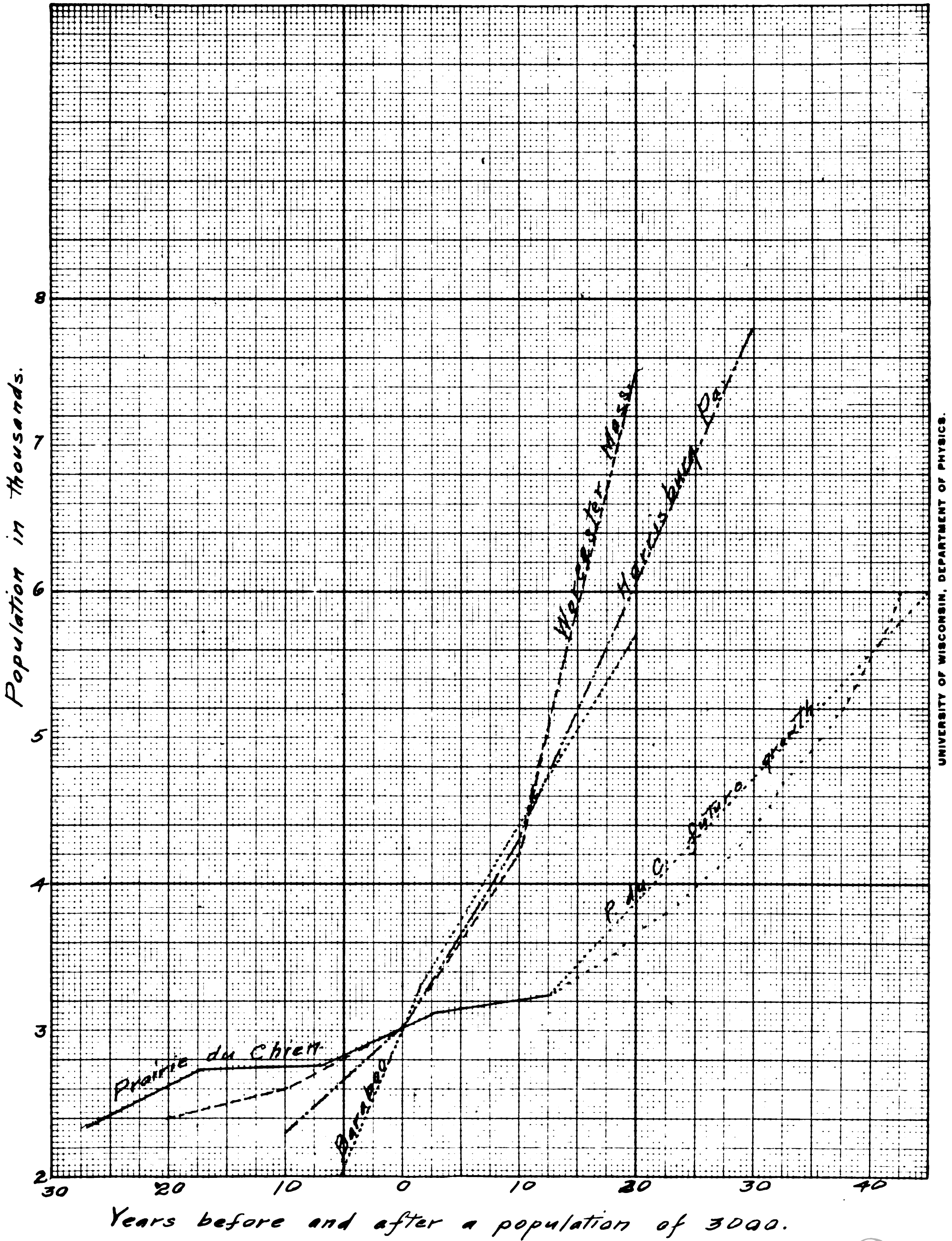

Population in thousands.
8
7
6
5
4
3
2
30
20
10
0
10
20
30
40
Years before and after a population of 3000.
Prairie du Chien
Baraboo
Worcester Mass.
Harrisburg Pa.
P. du C. future growth
UNIVERSITY OF WISCONSIN, DEPARTMENT OF PHYSICS.

Fig. 2

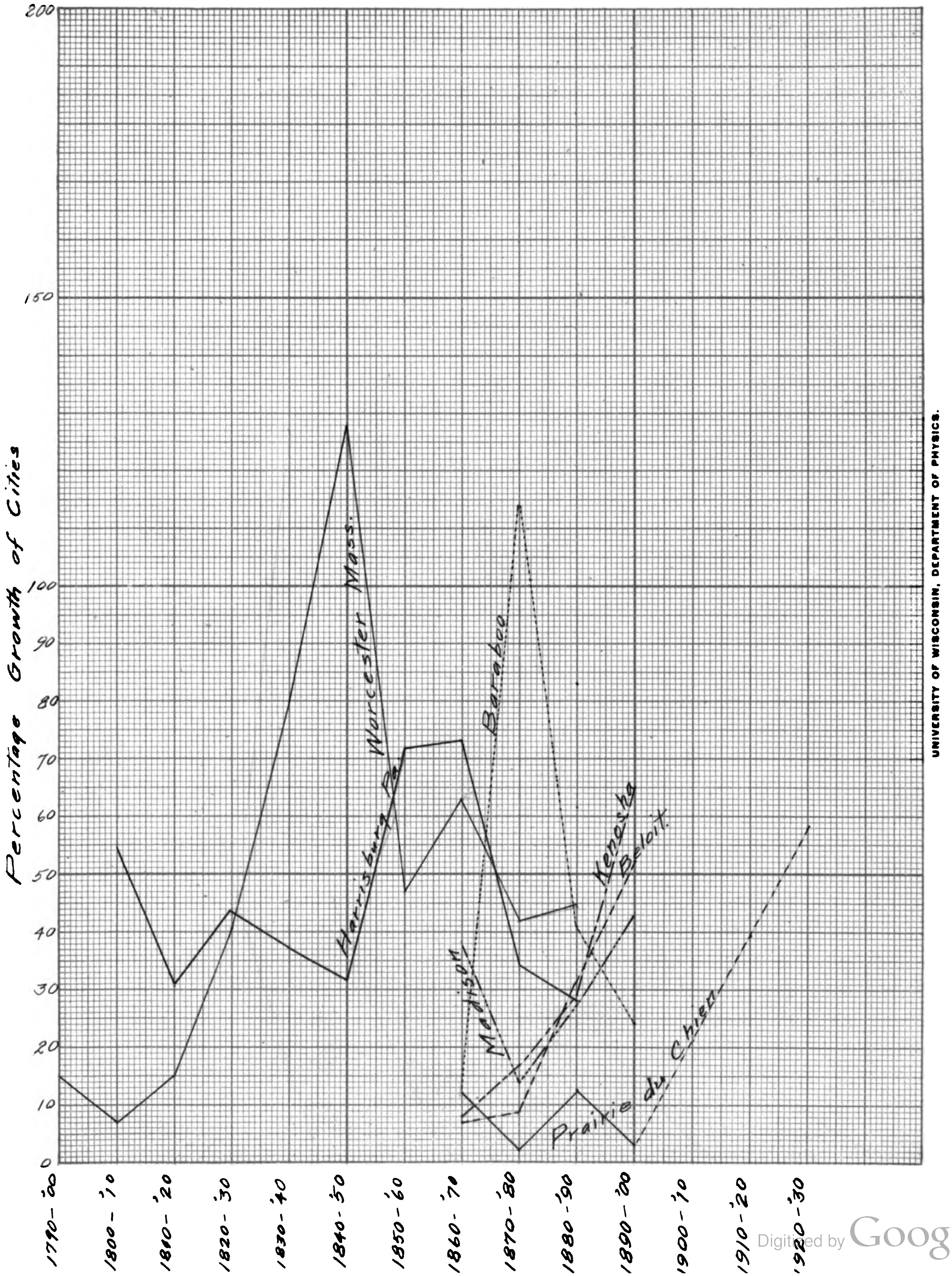

Percentage Growth of Cities
200
150
100
90
80
70
60
50
40
30
20
10
0
1790-'00
1800-'10
1810-'20
1820-'30
1830-'40
1840-'50
1850-'60
1860-'70
1870-'80
1880-'90
1890-'00
1900-'10
1910-'20
1920-'30
Worcester Mass.
Harrisburg Pa.
Baraboo
Madison
Kenosha
Beloit.
Prairie du Chien
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Fig. 4.

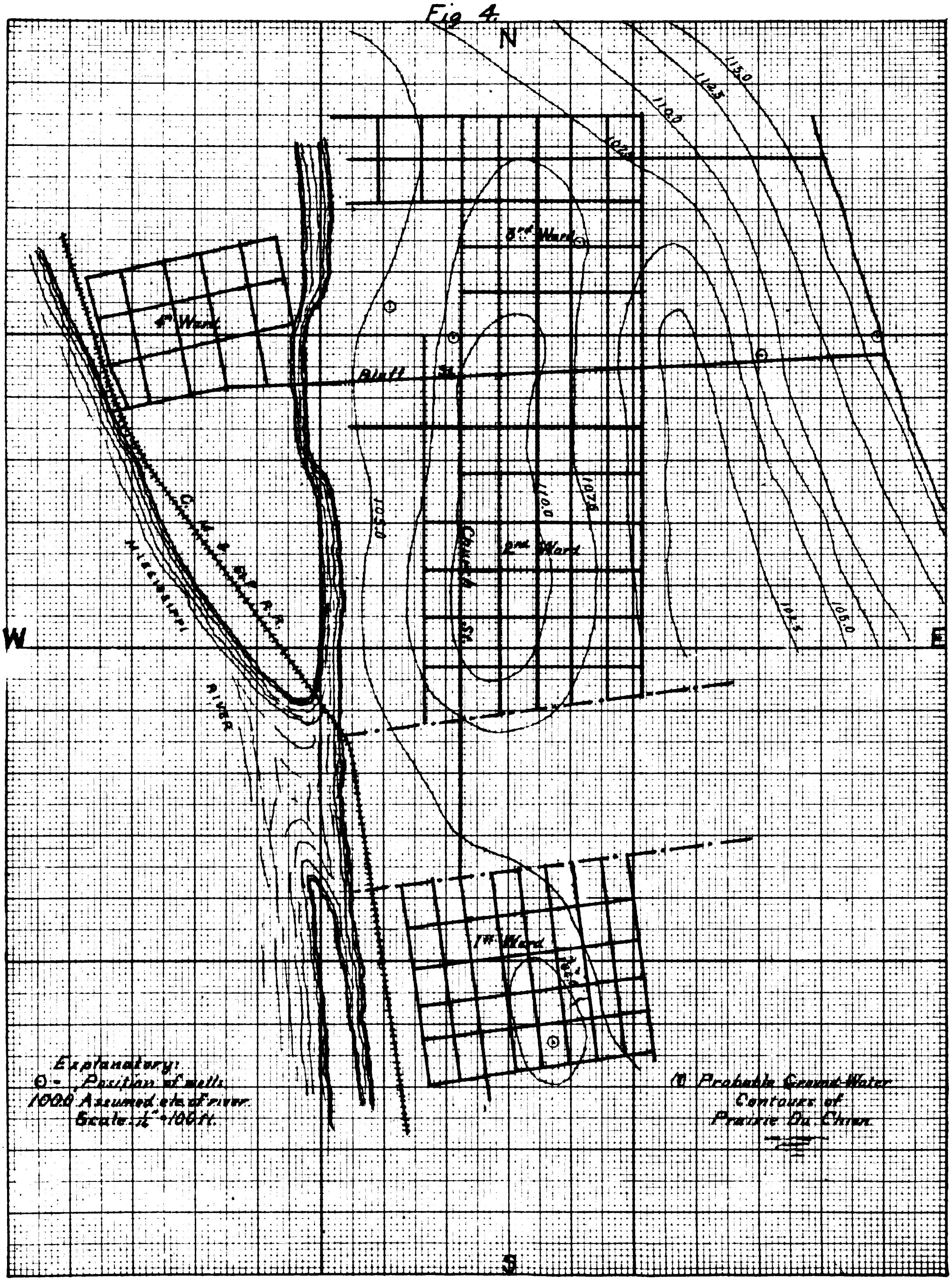

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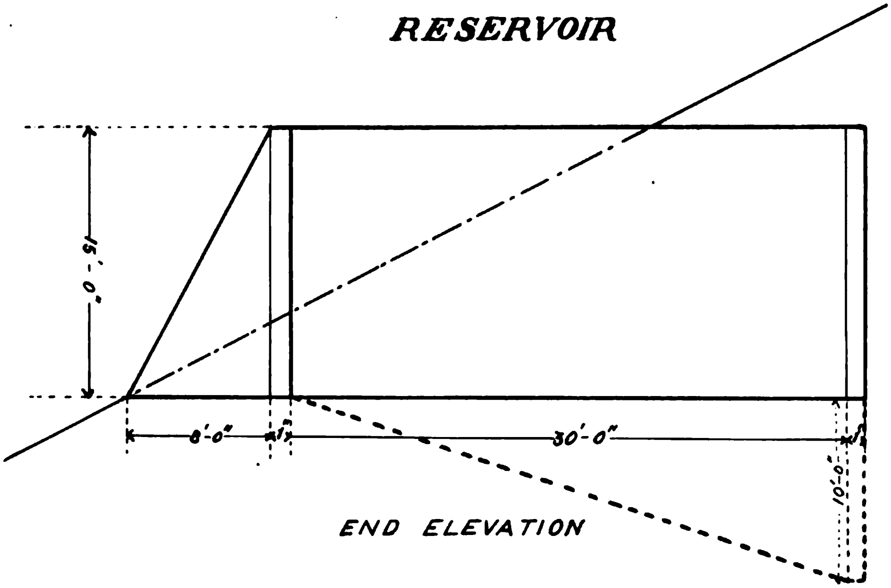
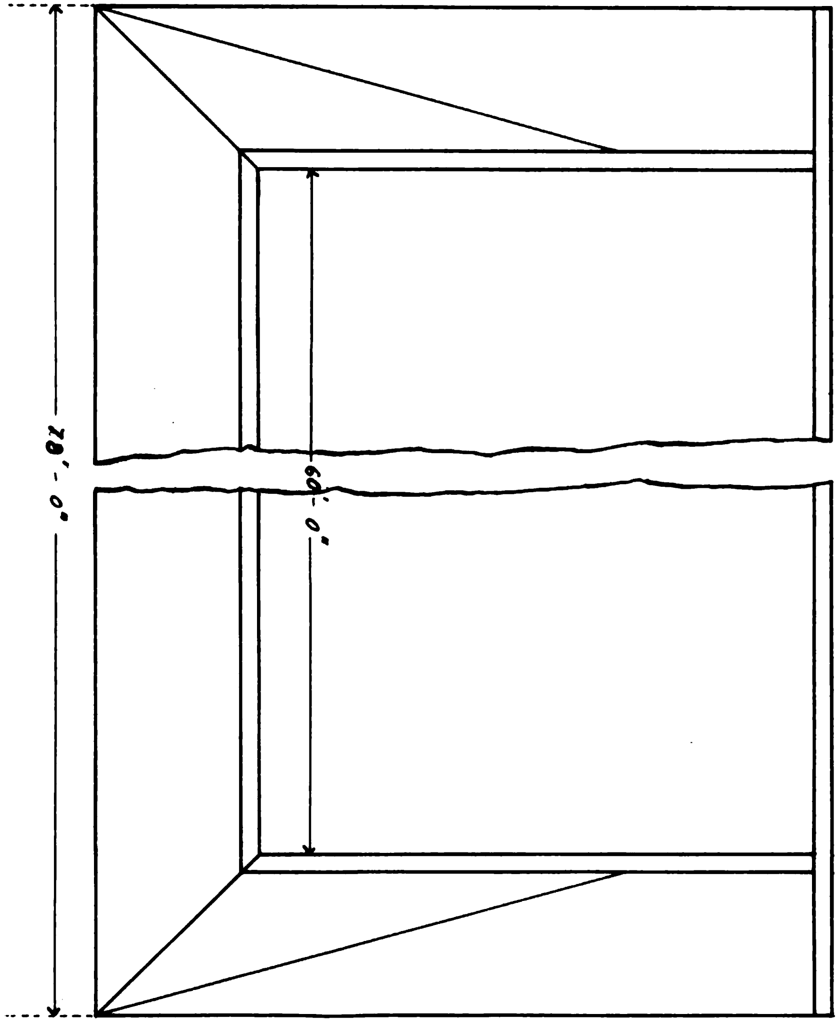
Fig. 5.

RESERVOIR



END ELEVATION



PLAN

Fig. 6.

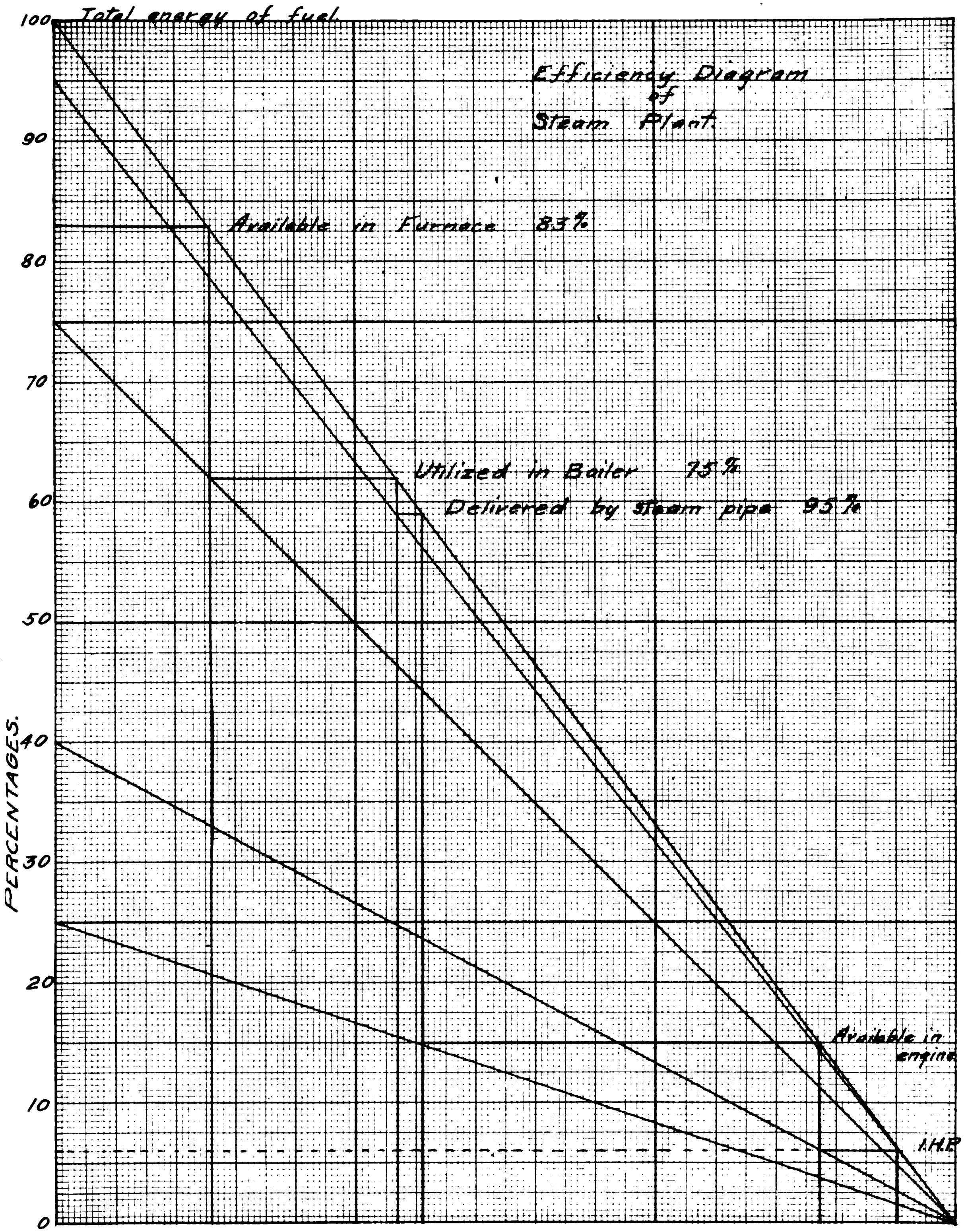


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Fig. 7.

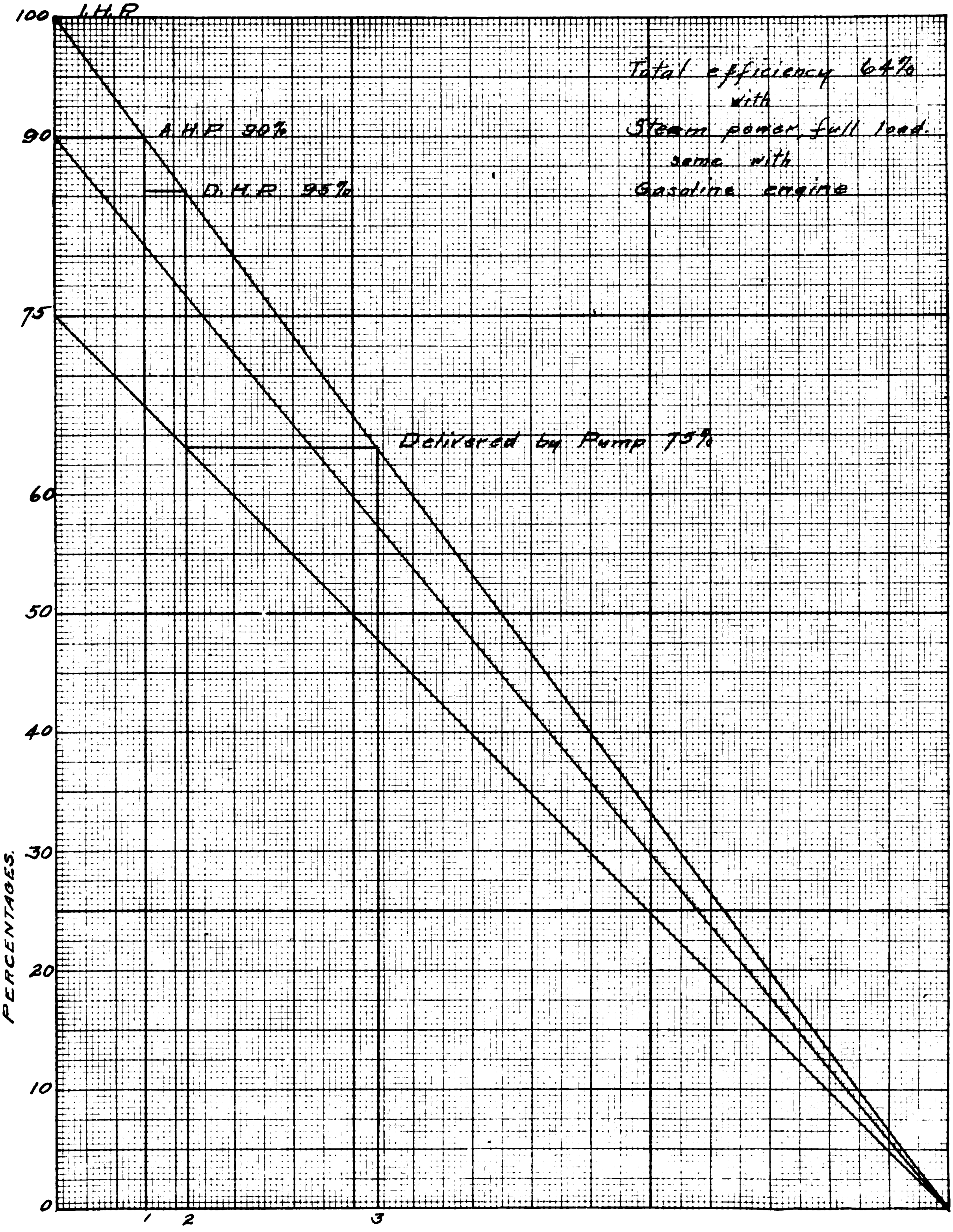

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Fig. 8.

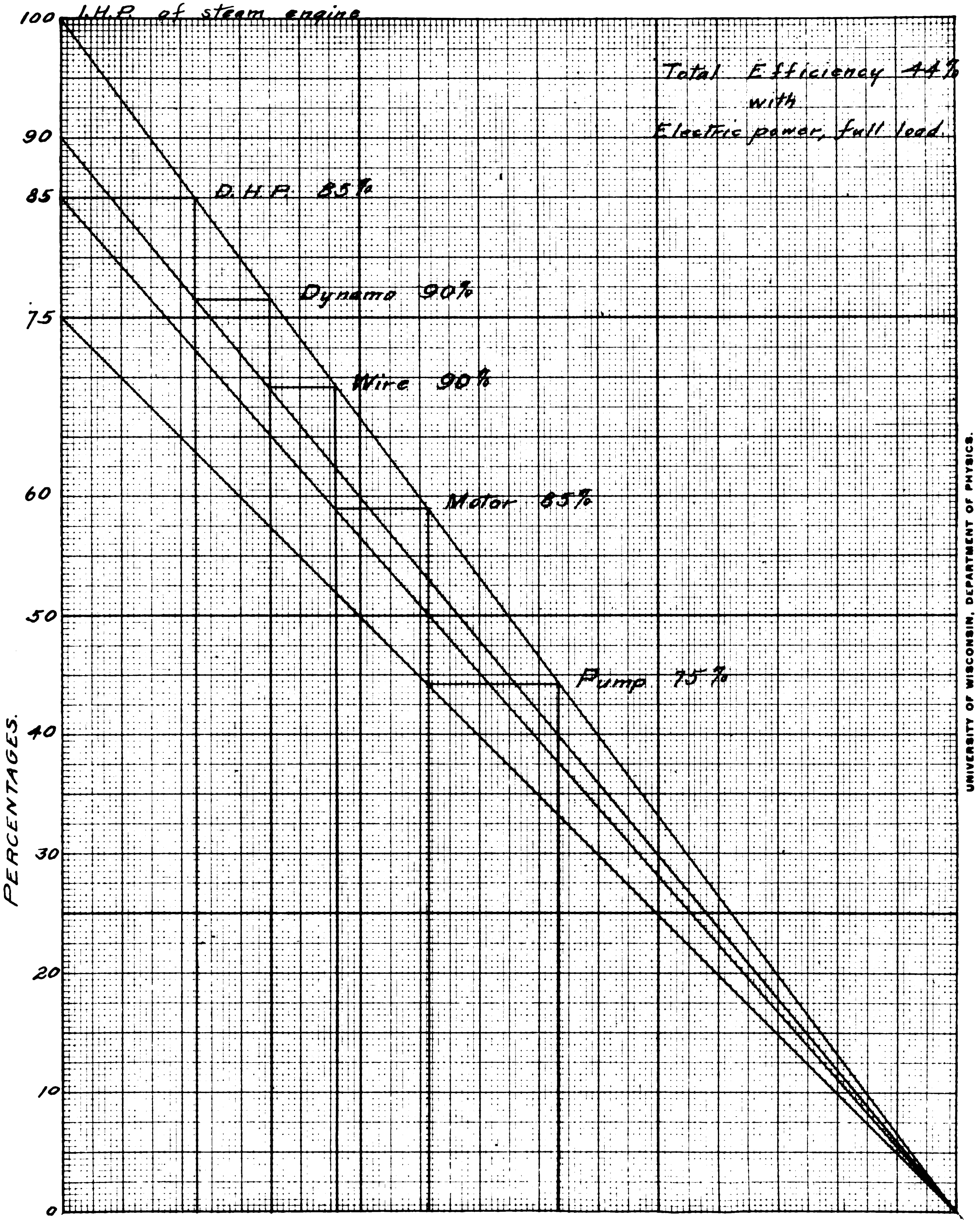

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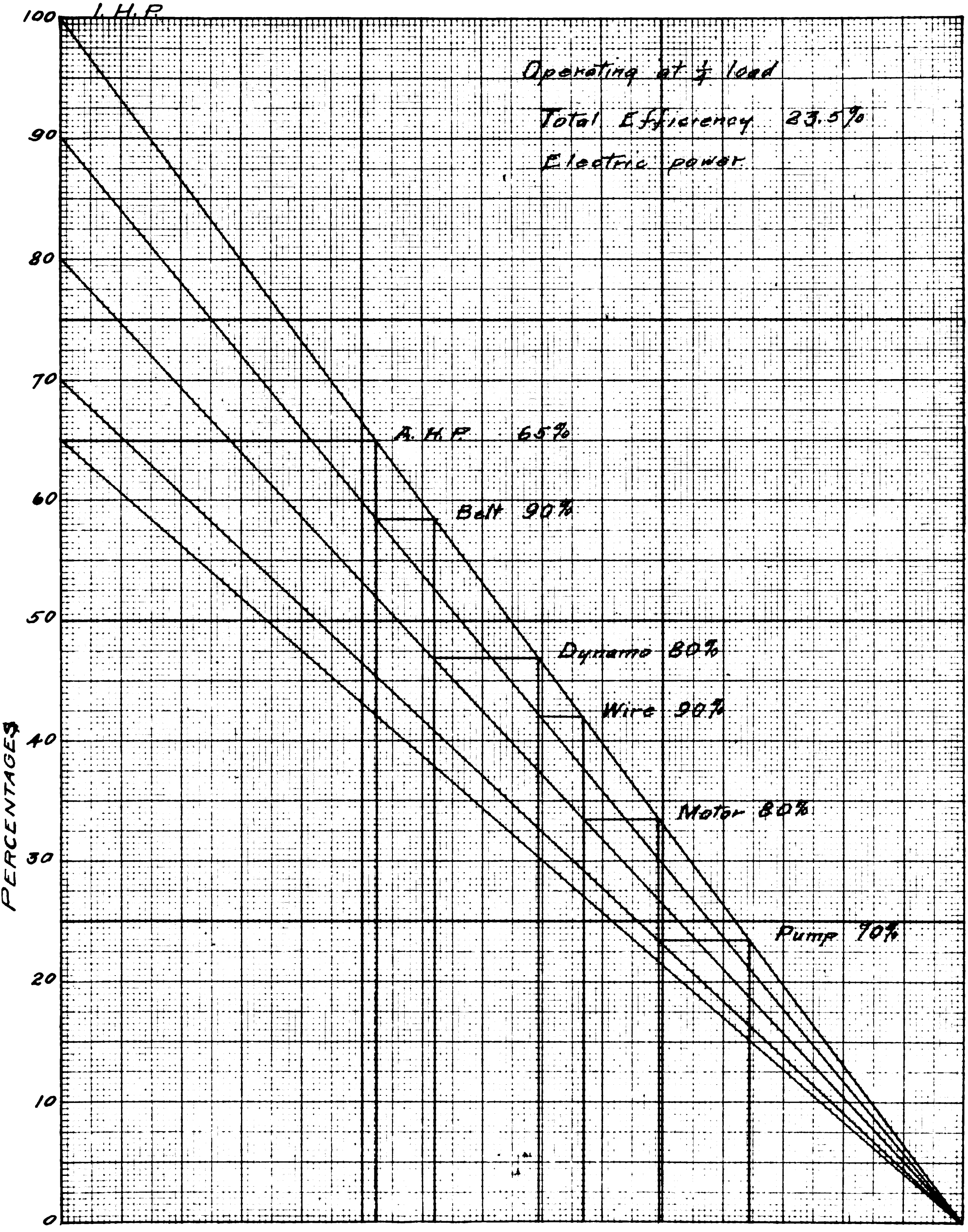
Fig. 9.



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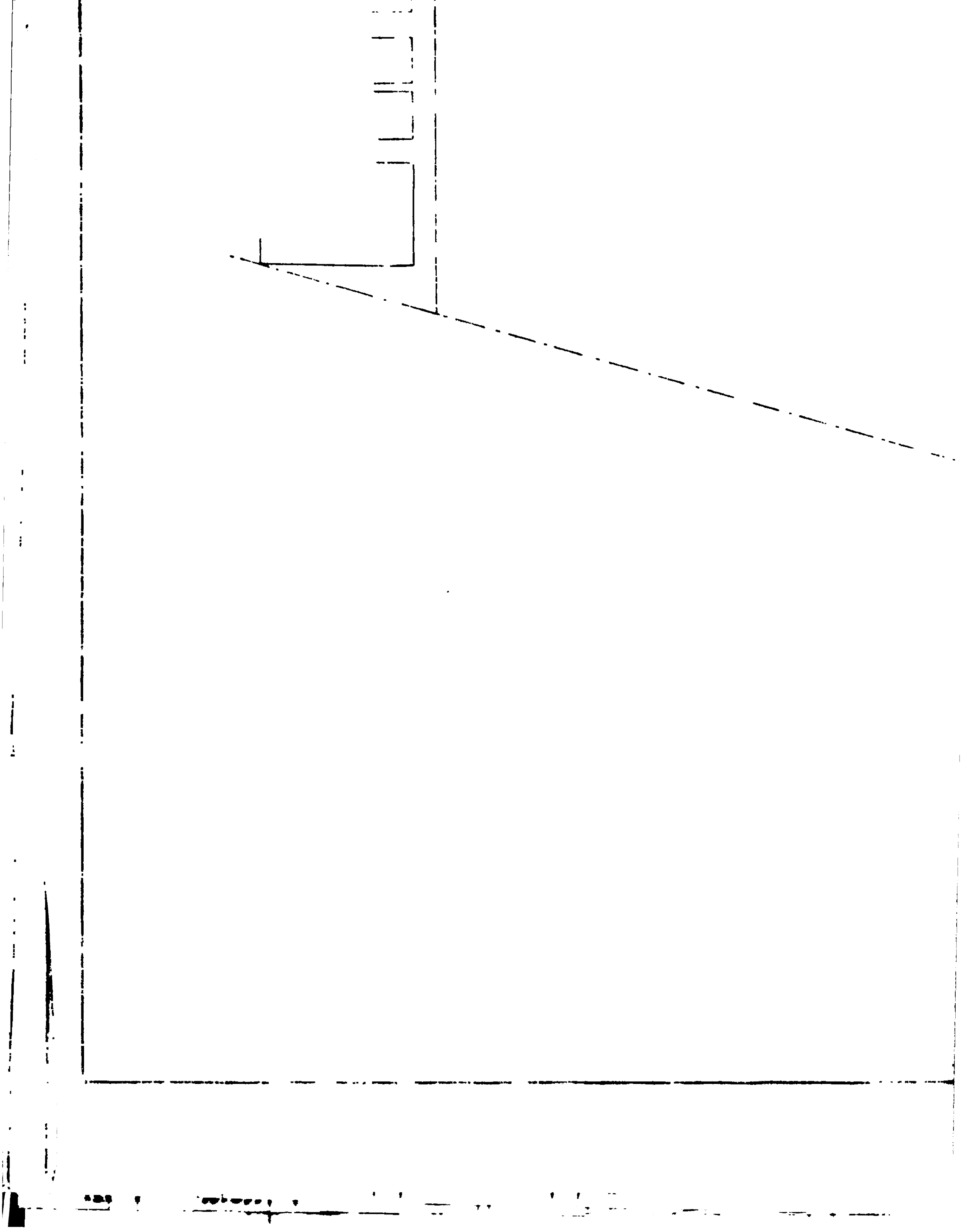
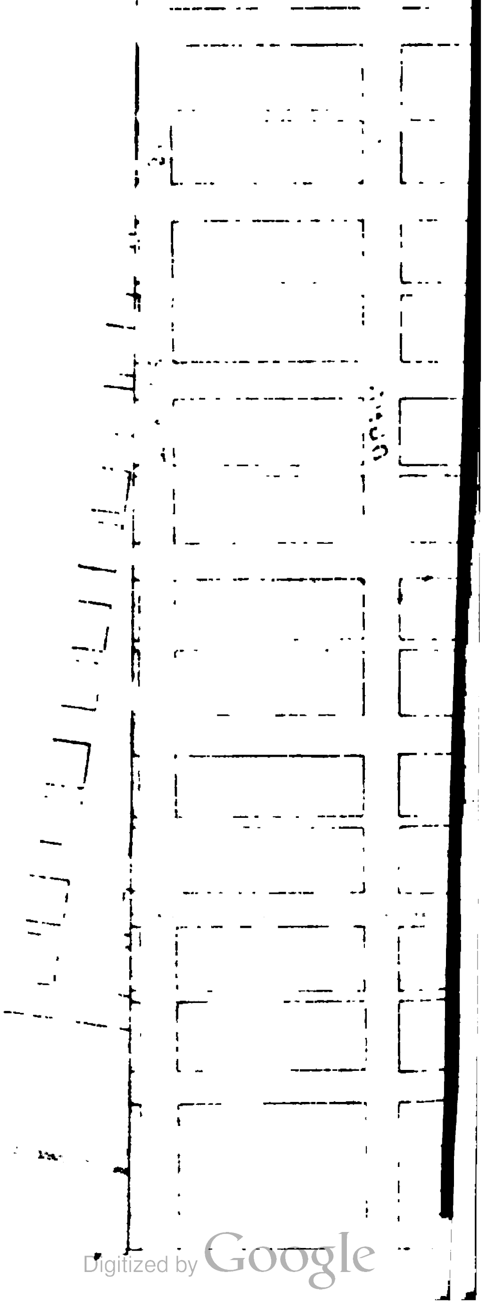
Approved
F. E. Turneaure
Prof. of Bridge & Sanitary Eng'g





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